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CIRCULATE AS MONOGRAPH

Ph.D.
(in Psych.)

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BY

G. G. BROWN

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VOL. XIX. PART 2, OCTOBER, 1928

Thesis for degree of
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PERCEPTION OF DEPTH WITH DISORIENTED VISION[1]

BY G. G. BROWN.

(*From the Psychological Laboratory, University of Toronto.*)

Introduction—factors in visual depth (pp. 117–120).

Derivation of the problem (pp. 120–121).

Definition and plan of the problem (pp. 121–123).

Apparatus and procedure (pp. 123–124).
  (*a*) *for disorienting vision* (p. 124).
  (*b*) *for measuring the limen of immediate depth* (pp. 125–127).
  (*c*) *for depth re-education* (pp. 127–129).
  (*d*) *for steadiness* (p. 129).
  (*e*) *for star-blanks* (pp. 129–130).
  (*f*) *for pursuit pendulum* (pp. 130–132).

Results: Part I. One week's continuous disorientation (pp. 132–137).
Part II. Effects with spaced practice (pp. 137–144).

Summary and Conclusions (p. 144).

Bibliography (pp. 144–145).

Appendix—on mathematical treatment of results (pp. 145–146).

INTRODUCTION.

Factors in visual depth.

BINOCULAR perception of depth may be analysed into two forms of experience. These will be called immediate depth and secondary depth, corresponding to what Helmholtz[2] calls "actual perception of depth" and "idea as to the distance." The former is dependent upon binocular disparity (dissimilarity) and upon the kinaesthetic factors of accommodation and convergence. The latter is dependent upon meaningful factors or distance clues in the subject matter, clearness, shadows, and so on.

---

[1] Presented in partial fulfilment of the requirements for the doctor's degree in Psychology, May, 1927. The writer wishes to make acknowledgment to Prof. E. A. Bott for direction and supervision throughout the experiment; to Mr S. N. F. Chant for advice upon the mathematical treatment of the data; and to those who together with Prof. Bott and Mr Chant co-operated as subjects, Dr Guyatt, Messrs Ketchum, Mumford, Alderson, and Mrs Brown. Acknowledgment is also due to Prof. Raymond Dodge, of Yale University, who first suggested the application of totally reflecting prisms to the requirements of this experiment.

[2] Helmholtz (9), III, 282.

Of the factors underlying immediate depth, disparity and convergence presume a binocular mechanism, while accommodation may operate when there is but one eye. Normally, however, accommodation is closely related to convergence although the relationship is not absolute and is subject to individual variations. On account of this relationship and the difficulties of ruling out any of these variables, the factors of binocular disparity, convergence and accommodation will be considered as one complex function.

The operation of this complex function in stereoscopy involves the presentation of stereoscopically dissimilar subject matter singly to the eyes, *i.e.* single dissimilar presentation. Following the terminology adopted by Bott in analysing the phenomena of orientation one may say that in the case of photographic material it has generally been accepted that the registration base of the pictures must be at zero inclination to the observation base of the eyes in order that full depth may be perceived[1]. In commercial stereoscopy, for example, registration by the camera is usually, though not necessarily, horizontal, and the pictures are then presented in a horizontal relationship to the respective eyes. Special effects of exceptional modes of presentation have, however, been noted[2]; for example, if the right-hand picture is presented to the left eye and *vice versa*, reversed or pseudo-depth results; and Helmholtz[3] noted that in the case of looking at natural objects, if the view as seen by each eye is vertically inverted normal depth is destroyed.

It has recently been shown so far as photographic materials are concerned that such observations are particular cases belonging to a general group of phenomena whose relationships may be subsumed under a law of orientation[4]. The instances above noted are only special cases of a large variety of possibilities covered by this general law. Registration and presentation conditions may be indefinitely varied. Thus pictures of objective data may be registered with a base at any position through 360°; these can always be fused when presented singly to the eyes, and will exhibit full natural depth if given an orientation to the observation base in accordance with the law of orientation. The optimum orientation for the pictures to be observed with full depth may be at any inclination through 360°, depending upon the conditions of registration.

---

[1] Bott (2), pp. 278–280. "The *registration base* is the hypothetical straight line joining the discrete locations from which each of a given pair of stereoscopic pictures is photographically registered." The *observation base* is simply the interocular line of an observer who views such pictures presented with an orientation definable in terms of their original registration.

[2] Brewster (4), pp. 84, 216; Le Conte (11), pp. 135 ff.

[3] Helmholtz (9), III, 308, 309.

[4] Bott (2), p. 291.

The circumstances of vision afforded by nature without instrumental assistance for the eyes is but one instance of the above principle, registration and observation orientation being here identical so that no inclination of the view is required by artificial means to secure the desired effect. Experimentation with stereoscopic pictures or drawings, however, has revealed certain additional and significant facts. Thus, whatever the registration conditions, the orientation required to secure full depth is not a point but rather a range of from 40° to 50° in extent[1]. Within these limits equally good depth is perceivable, while beyond them the depth effect is inferior and ultimately is reversed. Thus orienting the views beyond about 25° from the centre of the optimum range begins to reduce the quality of immediate depth. A deviation of 45°, clockwise or counter-clockwise, leaves the subject matter nearly flat. At 60° deviation it begins to be quite flat and continues so through about 60° more, with 90°, *i.e.* a right angle to the optimum, the centre of this range of flatness. Proceeding beyond the range of flatness, one finds that at about 135° deviation depth again begins to appear but is reversed in character. Further orientation from the original optimum increases this property until at 180° deviation there is the fullest degree of reversed depth. These ranges of modified depth as dependent upon orientation of the visual material are illustrated diagrammatically in Fig. 1, where the optimum orientation for full natural depth is taken to

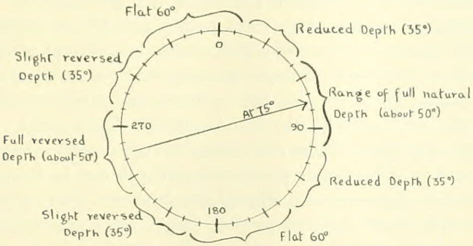

Flat 60°
Reduced Depth (35°)
Slight reversed Depth (35°)
0
Range of full natural Depth (about 50°)
At 75°
270
90
Full reversed Depth (about 50°)
Reduced Depth (35°)
180
Slight reversed Depth (35°)
Flat 60°

Fig. 1. Depth effects from orientating stereoscopic pictures whose registration requires an optimum orientation of 75° clockwise in order to give full natural depth.

---

[1] Bott (2), p. 286.

be 75° clockwise from the vertical. The ranges remain fairly characteristic in dimension whatever the optimum position may be as prescribed by the original conditions of registration.

In the case of complex subject matter, such as exterior scenes, reversed depth always involves considerable confusion owing to the clues for secondary depth being incompatible with the immediate reversed depth. The latter is perfect and unambiguous only when simple 'reversible' line figures (cone, tube, etc.) are used, reversed perspective being then as meaningful as the so-called 'normal' perspective.

Derivation of the Problem.

From these facts and principles certain questions arise. Granting that visual depth is consistently perceived whenever the subject matter is oriented in accordance with the above law, one wonders whether this outcome is due to inherent properties of the mechanisms of vision or is an acquired outcome dependent mainly upon the extensive practice imposed by physical nature under the restricted conditions of orientation that obtain in daily life. If depth perception is the result of a natural learning process, it is possible that practice under unusual conditions which at the outset afford little or no immediate depth would eventually lead to this experience. From this standpoint our problem is to ascertain whether and to what extent perception of depth can be learned under conditions of orientation experimentally imposed. Is it possible, for instance, with views oriented so that they appear practically flat, to learn by visual exercise to see them with an appreciable amount of immediate depth? Or again, can reversed depth be converted by visual re-education into perception of simple flatness or even into 'natural' depth?

Of the many possibilities that here offer for a training programme, it is clear that for practical purposes of experiment a selection must be made. The following considerations have governed our selection of conditions in order to test experimentally whether the perception of depth is in this sense an acquirable function:

First, to determine whether the law of orientation holds for observation of natural objects as well as of photographic material; and if so, to utilize the former as being a nearer approximation to ordinary visual conditions, including the factors of postural and ocular adjustment.

Second, to select for experimentation and practice a particular degree of disorientation of the fields which will afford an appreciable though not extreme modification of immediate depth. If the latter function is capable of re-education as a typical learning process this should give a favourable circumstance wherein any improvement could be quantitatively gauged. Any departure from this selected orientation would then be incidental and supplementary to our main point.

Third, to arrange experimental conditions which (*a*) can be maintained constant for different subjects, (*b*) will permit systematic visual practice, and (*c*) will permit the adoption of appropriate means for measuring the ability to perceive depth, before, during and after the period of training.

DEFINITION AND PLAN OF THE PROBLEM.

That means can be adopted for disorienting the natural vision field in lieu of being confined to the use of photographic material has been demonstrated by Stratton[1], and his classical experiment also proved the possibility of re-learning one's motor adjustment with a disoriented visual field. Stratton's experiment is very suggestive for our purpose, although his interest was not specifically in depth perception, and he therefore does not report upon that at any length. Stratton worked monocularly, wearing a system of double lenses which gave a field of natural magnification, disoriented 180° from its normal position, and reported to be 35° in size[2]. Under these unusual conditions he acquired the ability to co-ordinate vision and bodily movements and to look upon this 'turned-about' world as 'natural.'[3] For our task these conditions are not immediately pertinent. Two eyes rather than one must be employed for the investigation of immediate depth and a more quantitative method for gauging improvement is desired than a purely introspective report. It would be of interest, for example, to know something of the activity of the unseeing eye in Stratton's case and to have had a report upon the effect of transfer, if any, from the trained to the untrained eye.

A more important consideration regarding Stratton's technique with lenses prevents its adoption on a binocular basis. The rotation of 180° which lenses necessarily give the field is a fixed orientation which cannot be varied. When therefore the other field is similarly disoriented by lenses in order that the two may be fused binocularly, we unfortunately have that case of disorientation which gives the maximum degree of *reversed* depth. This is the result that the law of orientation would predict and the fact may readily be confirmed by trial. It involves a disturbance of depth phenomena too extreme to be overcome by a simple learning process.

---

[1] Stratton (13), p. 612.

[2] We have been unable by means of lenses to obtain a distinct monocular field as large as Stratton's, about 18° to 20° diameter being the largest we secured even with the assistance of the research department of a large optical company. The specification of Stratton's lenses is not given.

[3] Stratton (14).

As lenses give no other orientation than 180° it seemed necessary to seek an instrumental means of controlling the orientation of each field to any required amount through 360°. This was readily accomplished by means of two total reflecting prisms in tandem to each eye, as will be described below. The resulting field was smaller than Stratton's, being only about 10° in size but was fully controllable as regards the degree of orientation. With this prismatic device it became apparent that the law of orientation held in stereoscopy of the natural field as was already known to be the case with picture material.

The amount of disorientation chosen for the major portion of our experiment was 75° from the optimum position for normal depth. This is within the usual range for flatness but is near that extreme of the range where flatness begins and natural depth ceases. It thus avoids an extreme condition of flatness as well as an approximation to reversed depth. It was selected in preference to a position nearer that for optimum depth in order that observation and drill might be conducted at what may be termed the orientation limen of immediate depth. Such a limen, of course, is characterized by individual differences and is complicated by the presence of secondary clues depending upon the nature of the presented subject matter. Throughout the experiment disorientation of the binocular field was arbitrarily given in the clockwise direction. For comparison observations were taken by one subject with disorientation of a less and also of a greater amount than 75°, and another subject completed all the tests and exercises without disorientation of vision.

One disorienting apparatus only was used for all subjects. And in order to insure a proper and constant relationship of this apparatus to the subjects' eyes individual plaster casts of the upper part of the face were made for each subject to which the equipment could be fastened. This permitted the apparatus to be fixed firmly but comfortably before the eyes so that it could be worn either continuously or for limited periods.

The investigation fell into two parts. In Part I one subject, the writer, used the disorienting apparatus set at 75°, wearing it continuously for seven days from 18 to 25 September, 1926. This was undertaken in order to explore the process of adaptation to such a binocular field and was carried out in a manner suggested by Stratton's experiment. Short daily practices upon selected tasks capable of quantitative measurement were also included. An introspective account of this experience is reported together with some quantitative results.

In Part II, lasting from 27 January to 15 April, 1927, four subjects, G., M., K. and B., were each trained with disorientation of 75° on four special exercises according to a plan of spaced practice; one additional subject, F., was trained on these exercises at orientations of 45°, 90° and 135°; another subject, C., took training on all the exercises without disorientation. The exercises chosen required eye-hand coördination in one, two or three dimensions of space. The equipment to be described below consisted of a depth re-education apparatus, steadiness test, star-blanks for pencil drawing, and a pursuit pendulum.

Special attention was paid to testing the subjects. Two forms of measurement were used; first, finding the limen of immediate depth by a method of constant stimuli; second, finding a performance curve showing each subject's progress of adjustment to visual situations involving appreciation of depth. At the beginning of both Parts I and II of the experiment two limens were found for all subjects by means of a special testing equipment, namely, of ability to perceive depth without disorientation of vision and with disorientation of 75°. Comparison of the quantitative results obtained from these limens was intended to furnish a measure of the extent to which ability to perceive depth was impaired by a defined amount of disorientation.

The subjects were then trained and the data secured for their performance curves. At the conclusion of the training their limen with disoriented vision was again taken. The latter limen reading supplemented by the performance curve was to show each subject's progress of adjustment to visual situations involving appreciation of depth.

Finally, subject F., in Part II, in addition to the above training and testing, gave a set of limens for perception of depth with vision disoriented to various amounts less than and greater than 75°, viz. 0°, 45°, 90° and 135°. These were taken to indicate the amount of depth disturbance characteristic of other possible disorientations than that of 75°.

Apparatus and Procedure.

Two instrumental aids were employed in all phases of the experiment, namely, (1) apparatus for orienting the binocular vision field, and (2) a controlled objective field for visual or visual-manual observation. We shall first describe the construction and use of the prismatic goggles for orienting the field, and then in turn the equipment and procedure for testing limens of depth and the four training exercises already referred to.

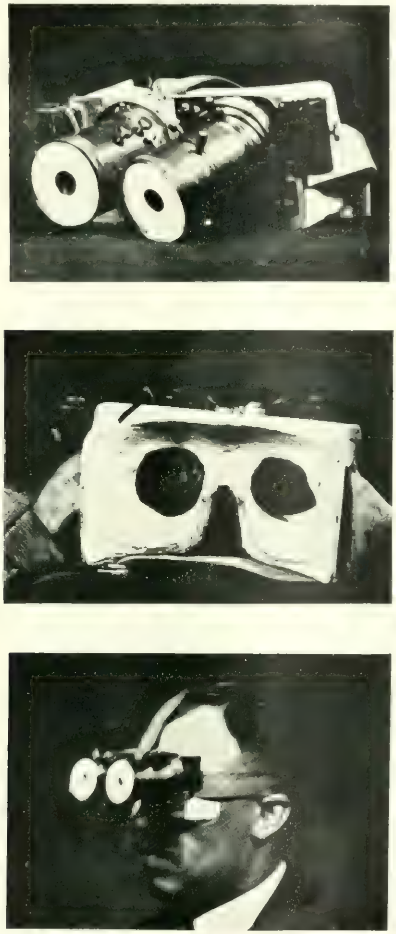
(*a*) *Apparatus for disorienting vision.*

This consists of a pair of goggles, each eye-piece consisting of a thin brass tube 4·5 cm. in diameter and 6·5 cm. long. Each tube contains two 1-inch right-angled prisms, one in front of the other. These are independently rotatable by being each set in an inner sleeve that can be operated through 180° by means of a small lever projecting through a slot in the outer side of the tube. Two prisms are used for each eye so that reflection of incident light occurs six times, an even number, and the images therefore are not laterally reversed as would be the case were a single prism used. By rotating one or other prism the effect called the 'leaning of the image' can be produced, that is, the visual presentation of the objective field to each eye can be disoriented any desired amount through 360°. The field can thus be shown either with or without disorientation, the latter being essentially the equivalent of normal binocular vision for the field of view concerned[1].

In our report angular disorientation is stated always in terms of the clockwise direction for the subject. With this type of prismatic control the field of view is limited in extent, subtending a visual angle of scarcely 10°, the field being delimited by an opaque cover with a central circular opening $\frac{3}{8}$ inch in diameter placed on the outer end of each eye-tube. The tubes containing the prisms are mounted on an aluminium plate which is screwed to a light plaster cast of the subject's face. The distance between the eyepieces can be regulated to suit the subject's interocular distance, and in addition one of the tubes (left) is attached to a double ring bearing which permits it to be set with any required inclination, horizontal or vertical, in order to facilitate binocular fusion for various distances without conscious strain. The right eye-piece is fastened rigidly in the primary visual position as it was found unnecessary for purposes of fusion to have both eye-pieces movable. Three adjustments of the movable eye-piece sufficed to provide fusion of external objects situated at any distance beyond 1 foot from the face. The whole apparatus is secured to the head by a strap passing around the back of the head and another over the top, joining the one behind. Plate I illustrates aspects of the disorienting apparatus.

---

[1] When wearing the goggles a subject can detect disorientation only by kinaesthetic means or by the meaningful character of the field; with a nondescript field he would be at a loss to know whether it was optically disoriented until he came into bodily contact with the visual subject matter.



Apparatus for disorienting vision.

BROWN.—Perception of Depth with Disoriented Vision.

(b) *Measuring the limen of immediate depth.*

Tests for the ability of depth discrimination were always conducted with the goggles on, whether or not the field was prismatically disoriented. This was to insure that as far as possible the factor of disorientation was the only variable affecting the limen results.

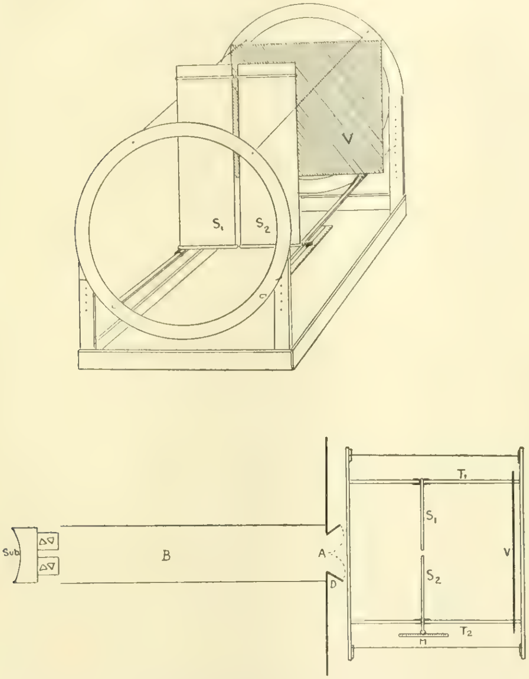


Fig. 2. Test equipment for measuring limens of depth perception. Upper, the unit with screens and background. Lower, a plan view of the complete equipment.

The objective equipment, Fig. 2, consists essentially of two screens, S_1 and S_2, of chalk-surface cardboard. The subject looks at these through the goggles and along a darkened channel, *B*, 97 cm. in length. At the remote end is an aperture, *A*, 15 cm. in diameter, opened and closed by a double shutter, *D*, under the control of the experimenter. As seen by the subject the screens S_1 and S_2 fill the field of the aperture *A* but their inner edges are separated laterally a distance of 1·7 cm., showing a black velvet background, *V*. The visual angle between the screen edges is 0·7°. The screens are mounted on tracks T_1 and T_2, along which they can be moved. S_1 is kept a constant distance of 136 cm. from the subject, while S_2 may be moved nearer or farther by the experimenter as measured on the millimetre scale *M*. Illumination is indirect and so arranged that to the subject the screens appear equally bright irrespective of their distance, their luminosity being about 13 foot-candles. The screens and their mountings are structurally connected in an outer framework consisting of two metal rings with inner diameters of 35 cm. This entire unit rests upon supports so arranged that the screen edges may be placed vertical or at any angular deviation therefrom. This provides that the screens can be objectively tilted if required instead of merely disorienting their images prismatically[1].

In Part I of the experiment grey screens instead of white were used, the aperture *A* was smaller, *i.e.* 7·5 cm., the distance of the stationary screen 115 cm., and the illumination was weaker[2]. With these objective conditions the following procedure in finding a limen was tried. With S_1 stationary, S_2 was placed in arbitrary positions, front, back or even, to a limit of 35 mm. in either direction, using steps of 5 mm. The shutter was closed during manipulation of the movable screen. The subject reported whether S_2 appeared farther, nearer or even as compared with S_1; eight presentations for each position were made in miscellaneous order. That distance where half of his reports were 'even' and half correct was taken as the limen distance for depth discrimination. This plan was not free from ambiguity, since frequently for a given position of S_2 a preponderance of correct responses would be accompanied by responses favouring the opposite direction, so that consistent interpretation of the results was difficult. The limen values here secured are given later.

In Part II the test apparatus was modified to the form first described and the procedure was varied in the following particulars. Stimuli were given in fifteen equally spaced positions, one even, seven with S_2 nearer, and seven with S_2 farther than S_1. The size of the steps was determined by preliminary trials with each subject, and they were so graded that the seventh step near or far was at the least distance at which complete accuracy of response was approximated. The subject was required to report 'nearer' or 'farther.' No 'doubtful' or 'even' responses were permitted and a response was required to each stimulus by guess if necessary.

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[1] Except in certain exploratory tests upon a subject whose results are not reported, the screens were used only with their edges upright throughout this experiment.

[2] It would have been preferable had the apparatus and procedure been exactly the same in each part of the experiment. From his experience as subject in Part I, however, the writer concluded that certain refinements were desirable and these were adopted for the subjects in Part II.

From the readings obtained by this method of constant stimuli the values of the phi-gamma curve that most nearly approximated the distribution of responses were found. This curve was chosen because it has been experimentally demonstrated[1] that it approximates more closely than any other mathematical curve to the data obtained in psychophysical work. The values can be calculated by the use of Urban's tables[2]. Three quantities are involved: (1) h, a measure of the precision of the curve, (2) L, the limen, where 50 per cent. of the responses are correct as calculated from all the data, and (3) sigma of the distribution, where sigma is the reciprocal of h times the square root of 2.

In this experiment h is the most significant value since an increase in it means an increase in the precision of response. For these data L is really a measure of constant error, for if the errors are equally balanced, L will be zero whatever the size of the errors; it increases if errors preponderate one way or the other. Sigma is the value actually used in the construction of the curve of which L is the mathematical mid-point. At the end of this paper one complete set of data is given showing in detail the method of computing these values.

The method of constant stimuli was considered preferable to a gradation or reproduction method because it permits control of two factors, duration and number of exposures, and because it permits utilization of all the data in determining any given value.

(c) *Depth re-education apparatus.*

The endeavour here was to arrange a simple objective field wherein objects of identical appearance would be viewed against a plain black background and appear to be in mid-air without visible support (see Fig. 3). Three brass discs D_1, D_2, D_3, each 2 cm. in diameter, are arranged in a row with centres 3 cm. apart. Each disc is mounted on the near end of a straight metal rod, the latter being concealed by its disc from the subject. These rods project in parallel lines through openings in the velvet-covered background, V. The rod carrying D_2 is stationary with its disc 6 cm. in front of *V*. Discs D_1 and D_3 can be made to advance or recede any distance up to 12 cm. in front of *V* by means of non-elastic endless cables reaching from behind the background towards the subject below his field of vision and attached respectively to two sliding lugs L_1 and L_3 which the subject may grasp. A millimetre scale indicates the position of the discs. Seated 125 cm. from the background, the subject may operate L_1 and L_3 with his hands and thereby operate D_1 and D_3 in a like direction and amount as though he were grasping these discs themselves. The purpose of this arrangement is to dissociate the kinaesthetic from the visual control so that the former will not be confused by the disorientation given to the vision field, as would be the case if the subject's hands were in his field of view. A stationary lug L_2 is given a position corresponding to the stationary position of the disc D_2. The subject can therefore have full kinaesthetic knowledge of the objective placement of the three visible discs irrespective of their apparent relative placement purely in terms of visual depth. The apparatus was designed to pertain as exclusively as might be to the third dimension of visual space; increase or decrease in the apparent diameter and lateral separation of the discs as they moved was not eliminated but was for the most part below the threshold of accurate discrimination. The expectation was that with visual depth destroyed by prismatic disorientation of the field, the eyes might be re-trained in this capacity by means of the manual kinaesthetic field which remained unimpaired and unaffected. Full investigation of this thesis will require more extensive drill than was possible with our subjects.

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[1] Urban (20).

[2] Boring (18); Brown and Thomson (17), Ch. III.

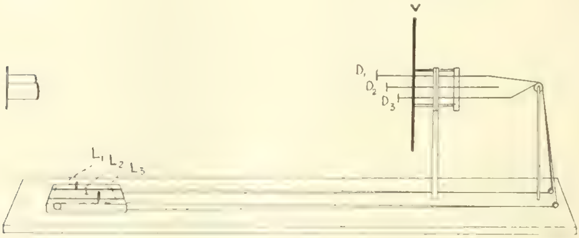


Fig. 3. Re-education apparatus. Description in the text.

This apparatus was available only for Part II of the experiment; the following was the procedure adopted. The movable discs, D_1 and D_3, were set by the experimenter and the subject was required to adjust them until they seemed even with D_2 working only with visual knowledge. Sometimes D_1 and D_3 were both set in front of D_2, sometimes behind, sometimes one in front and one behind. The subject was sometimes asked to set each separately, sometimes simultaneously. After setting them so that they seemed even with the stationary disc, his error was recorded, and he was then told to set them even from the tactual and kinaesthetic clues furnished by the stationary lug. The score for each day's practice was the average error in millimetres of the settings on pure visual clues. To ensure that no setting was made by absolute kinaesthetic sense the distance of the movable discs from the stationary one was varied from 4 to 6 cm. On this exercise subjects worked for ten minutes on each of the first ten sittings and for five minutes on each of the last six occasions. Sittings were on the average three times per week.

(*d*) *Steadiness apparatus.*

This is of the conventional type; the plate contains fourteen holes, graded from 1 to $\frac{1}{8}$ inch in diameter and has $\frac{1}{2}$ inch clearance above the wooden base. The stylus is $\frac{1}{16}$ inch in diameter and has a handle 12 inches long set at right angles in order that the subject's hand may be outside his field of view.

The task was to insert the stylus in successive openings to a distance of $\frac{1}{2}$ inch without touching the sides, beginning from the largest hole. Withdrawal performance was not considered as this was dependent on manual kinaesthetic rather than visual control. The score was the total openings entered without contact; no basis of weighting was employed, nor any time limit imposed; only one trial per hole was permitted. Four full performances were taken at a sitting and the scores of the last three taken and averaged.

This exercise demanded eye-hand co-ordination in three dimensions of space and was a much more difficult performance with vision disoriented than ordinarily.

(*e*) *Star-blanks.*

These were of the type frequently used in mirror-drawing, six pointed, $3\frac{1}{2}$ inches in diameter, pathway $\frac{1}{8}$ inch in width. Time was taken to the nearest second. Touching or crossing a boundary constituted an error. Subjects were instructed that both time and errors counted against them and were told to stop and move to the centre of the path each time they touched a line. Three to ten figures were completed within the period of a sitting and the results averaged. Time and error scores were not combined.

This exercise was selected as involving two dimensions of space, near-far and right-left. It was expected that this exercise would be more difficult than ordinary mirror-drawing because disorientation of vision at 75° disrupts co-ordination in both of these dimensions and to an unequal extent, whereas drawing in a plane mirror interferes only with one of the three dimensions of space. Both introspectively and from the objective results, however, it did not prove more difficult than mirror-drawing, although this was not the case with a greater disorientation, for example, 135°.

The star-drawing above described was substituted in Part II of the experiment for star-tracing which had been utilized in Part I. The latter consisted of tracing on thin paper a figure of eight radiating lines, each 1 inch in length. This performance was not timed and was scored on the percentage of lineal distance accurately superimposed.

(*f*) *Mechanically operated pursuit pendulum.*

In this equipment, Fig. 4, the pendulum is a light brass tube 1 cm. in diameter and 95 cm. long, suspended through an opening in the centre of a horizontal worm-gear wheel 4 inches in diameter. The pendulum is on strong point bearings attached to the upper surface of this gear wheel, and the latter rests on a circular metal rim attached to the main supporting frame so that the gear wheel may be made to revolve and carry with it the pendulum and all the upper mechanism that actuates it. The latter mechanism consists of a small motor, dry cells and a small worm-gear with an eccentric driving shaft attaching to a sleeve on the pendulum above the point of suspension. Starting this motor oscillates the pendulum in a given direction. The amplitude of swing is altered by adjusting the position of the sleeve on the pendulum and the rate of oscillation is controlled by a rheostat in this motor circuit. The pendulum can thus be given any rate and any amplitude of swing and will maintain a high degree of constancy.

A second motor on the floor actuates the worm that engages the main horizontal gear wheel and thereby revolves the whole pendulum unit at any desired rate through 360°, with the result that no two swings of the pendulum are made in the same direction. The pursuit movement is thereby made a two-dimensional one as well as a co-ordination for speed and range. The direction of rotation of the pendulum unit was changed at least once during each sitting.

The pendulum nozzle is made to deliver a very small unbroken stream of water, an upper reservoir delivering water into the pendulum through a similar sized nozzle so that the weight of the pendulum is not altered. A tubular receptacle 1·8 cm. in diameter with a handle is used to catch the water, the remainder falling on a large inclined drip pan. This receptacle and the drip pan are each connected by light tubing with graduated glass containers so that the proportion of liquid caught to the total discharged is at once apparent. A coarse netting of fine copper wire immediately beneath the pendulum prevents the receptacle inadvertently striking the pendulum when in action. Short metal flanges projecting from the rim of the receptacle assist in keeping it from becoming caught in this protective netting.

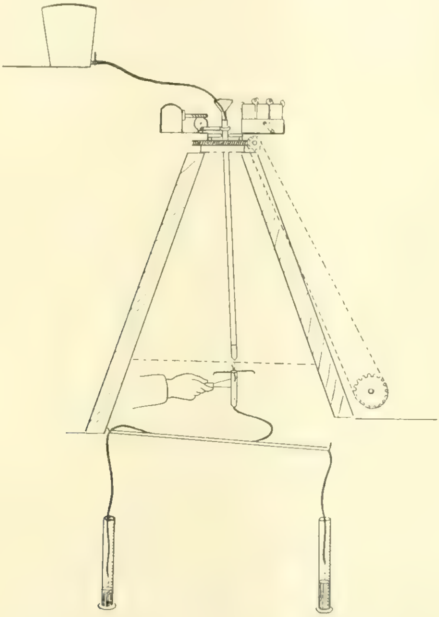


Fig. 4. Mechanical pursuit pendulum, with quantitative recording of performance.

The pendulum was driven at a speed of 16 double oscillations a minute with an amplitude of 36 cm. At the same time it was revolved through 360° every two minutes so that each swing returned in a plane approximately $22\frac{1}{2}$° distant from that in which it started. The subject sat about 70 cm. from the central position of the nozzle, but this distance was not constant as he was allowed to move the body freely. The score for each practice is the percentage of water caught out of the total flow.

This proved to be a very satisfactory two-dimensional exercise, particularly on account of its active character which does not leave the subject at liberty to make his visual-manual adjustments when and how he will.

Results.

Part I. One week's continuous disorientation.

In this part of the experiment one subject (the writer) was first tested on the limen apparatus for ability to perceive depth with and without disorientation. After wearing the goggles for a week he was again similarly tested. During the week he took daily practice on the steadiness, star-tracing and pendulum exercises. Below are the results of the depth perception limens, quantitative performance on exercises, introspections, and some conclusions.

Depth perception limens.

(*a*) The limens without disorientation of vision before practice were:

When movable screen was front	15 mm.
,, ,, back	15 mm.

(*b*) The limens with disoriented vision before practice were:

When movable screen was front	30 mm.
,, ,, back	30 mm.

(*c*) The limens with disoriented vision after practice were:

When movable screen was front	20 mm.
,, ,, back	25 mm.

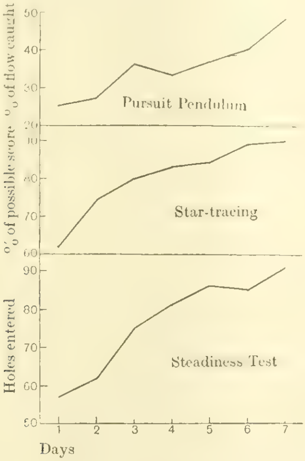
In (*a*) and (*b*) there were no ambiguities in determining the limens according to the criteria adopted. In (*c*) the distribution of responses for backward displacement at 20 and 25 mm. respectively was:

At 20 mm.: 4 back, 2 even, 2 front.
At 25 mm.: 5 back, 2 even, 1 front.

The latter value was accepted as more nearly satisfying the criteria.

Comparison of the limens for undisoriented vision with those for disoriented vision before practice shows a marked loss of immediate depth when vision is disoriented 75°, the amount of displacement of the movable screen necessary to experience immediate depth being double that required when vision is undisoriented.

Comparing the limens for disoriented vision before and after practice shows that the latter limen is appreciably smaller, which might be interpreted to mean that depth perception under these conditions had improved by drill approximately 25 per cent. This conclusion must be accepted with reservations; first, because the result may be partly or mainly due to adaptation to the general conditions imposed by the nature of the experiment, instead of to changes in the functioning of the specific ability we wish to examine; and second, because of the deficiencies of the procedure, already noted.



Graph 1. Daily performance of subject B. on three exercises during one week's continuous disorientation at 75°.

Quantitative performance on exercises.

Steadiness. There were ten recorded practices per day on the steadiness tester, each preceded by an unrecorded practice. The daily scores are shown in Graph 1, expressed in terms of total openings entered per day without touching. It will be seen that the score increased fairly consistently from 57 on the first day to 91 on the seventh.

Star-tracing. Twenty of the radiating figures were copied per day. The percentage of accurately superimposed lines is also given in Graph 1. Efficiency increased from 62 to 90 per cent.

On the pursuit pendulum there was about 15 minutes actual practice per day broken irregularly by short rests of a few minutes. On the first day 25·4 per cent. was caught, on the last 48·5 per cent. An initial control performance without disorientation gave a score of 77 per cent.

The quantitative results in all of the exercises are in agreement to the effect that adaptation to disorientation of 75° was proceeding in a fairly uniform manner throughout the week.

Introspective results.

The goggles were put on at noon, 18 September, 1926, and until midnight, 24 September, they were taken off only for short rests and upon retiring. Whenever they were removed the eyes were carefully blindfolded so that only disoriented vision was experienced during this period. Under these circumstances the subject lived in his apartment, walking through the various rooms, looking out at the street, attempting (unsuccessfully) to read, and performing certain ordinary acts such as bathing, shaving, eating at table, and so on. Some of the apparatus for the quantitative exercises was at the University, a half-mile distant, so the subject went there every evening. The goggles being too unwieldy to wear during the trip, he was blindfolded and guided.

The major initial difficulties for the subject were awareness of the tilted position of the objective world with consequent embarrassment in dealing with objects such as furniture, etc., and the fact that when the head was turned the entire field of objects seemed to move (in the opposite direction to the head rotation). These factors resulted in a somewhat chaotic state of mind and a slight dizziness. A tendency to nausea also shortly ensued. It would have been of interest to see to what extent this dizziness and nausea would have persisted, but in order to proceed with the experiment as planned the subject took chlorotone in moderate amounts and rested with eyes closed whenever these symptoms showed signs of increasing. This was found necessary twice on the first day, and once on the second day, after which neither dizziness nor nausea was evident.

The tilting of the objective world was less noticed as time went on. Even by the end of the first day adaptation to this feature had rendered it inconspicuous, by the end of the second one could scarcely conceive the perceived walls as inclining 75° from an imagined visual normal, and any such interpretation became harder every day. The new perceptual situation, however, never became quite 'natural,' although during the last half of the week's experiment both the fact and the amount of inclination seemed to be very uncertain.

Parallel with this adaptation it became easier for the subject to move about in his rooms. The first attempts at walking were cautious and slow. Door-frames seemed to be directly across the path, and to pass them required much groping. These difficulties remained very great even at the end of the second day. During the third day the subject walked across interior spaces with more confidence. By the fourth day doorways could be passed without studying them or touching them; they were still inclined, but the inclination seemed less, and their visual position seemed to bear a closer relationship to the behaviour required to pass them. By the last day a door could be passed without special attention, and, although the inclination still seemed 'unnatural,' postural adjustments were readily and quickly made.

The problems presented by objects on the floor, even though their relative positions were known from previous experience, were much harder to deal with. When looking at a chair, for example, at the distance of a few feet and below the level of the eyes, disorientation affected more than one spatial dimension, and the relationship between the visual and the kinaesthetic position could not be reasoned out. Even at the end of the experiment it was impossible to sit down without the assistance of the hands, although this had become less difficult with systematic practice. It was harder still to perceive and react to groupings of furniture whose spatial relations were not previously known. In the rooms in which the subject spent most of his time, where the arrangements of furniture were nearly constant, learning to 'see' them correctly was almost, but not entirely accomplished. In visiting the laboratory, the tables, chairs and apparatus had been rearranged after the subject had put on the goggles and an accurate idea of the new arrangement was never correctly formed. Cautious groping around the room was here necessary and only a slight improvement in this adjustment had occurred by the end of the week. Contact with unknown groupings of objects on the floor always caused some initial bewilderment.

Judgment of near distance (within range of the hands) seemed to improve rapidly. The subject shaved every morning and the time of this operation was reduced from about half an hour on the first day to seven minutes on the last. He used ordinary cutlery at all meals. On the first day it was only by trial and error that the food could be managed by fork or spoon; by the third day this had become fairly easy, and articles on the table could be picked up without fumbling. By the fifth day the procedure at table seemed perfectly normal and no further attention was paid to practical problems of this sort. This type of learning was probably facilitated by playing games of 'patience.' At first the process of laying out the cards in position proved extremely laborious, by the evening of the third day a fair degree of speed was possible with only slight confusion, and during the last three days the game could be played with no difficulties, except those that arose from the restricted size of the vision field.

Whether improvement in the manipulation of near objects means that perception of depth had become more exact is not easy to decide. It was difficult at first for the subject to judge his distance from a familiar piece of furniture, but his rapid improvement in this respect may have been due mainly to previous knowledge of his environment. When special attention was directed to certain features of his surroundings illusions of reversed depth sometimes appeared and frequently persisted. An abutment from the wall above the fireplace was as often as not seen as a shallow alcove, in spite of the fact that it was looked at with knowledge. Whenever objective secondary clues were available this kind of illusion rarely appeared and never persisted. For example, of two chairs close together, the nearer sometimes seemed farther for an instant, but a clue from superposition would suffice immediately to banish this illusory effect.

Another initial difficulty, the apparent movement of the field when the head was moved, progressively decreased and disappeared. In the early stages the movement seemed to be entirely referred to the objective field. There followed an intermediate stage in which both the field and the subject seemed to share in this phenomenon of movement, but by the fifth day all projection of the subject's movement had disappeared.

Visual imagery was operative, but imagery of the new sensory type was slow in taking precedence over that of previous visual experience. Sometimes imagery of the new experience appeared and persisted faintly for a few moments after being blindfolded, such persistence increased slightly each day, but normal imagery always returned. On the other hand, it gradually became possible to think of the contents of the apartment in terms of the new imagery and the latter sometimes completely superseded the older type. For example, it became easy to think of the doors as tilted when the subject was looking at a tilted picture on a tilted wall. When thinking of relationships outside the apartment, for example, imagining streets through which the subject was being guided, the old imagery held complete sway. The experimenter ordinarily enjoys strong visual imagery.

When the goggles were taken off at midnight of the seventh day the subject's visual experience did not seem unusual. There was some dizziness for about five minutes during which it was difficult to walk. This dizziness was greater than that experienced the first day the goggles were worn, though possibly this would not have been the case had chlorotone not been used as mentioned. It was very difficult to fixate an object, things seemed to jump with the attempt to do so. No similar difficulty had been experienced during the experiment. There was now a great amount of eye fatigue which had not been conspicuous while the goggles were being worn; when examined next day there was notable hyperemia of the eyes. One slight difficulty of re-adjustment was a tendency to limp, due to coming in contact with the ground to the left sooner than expected. This persisted for about an hour but was evidently more pronounced to the subject than to others since two or three persons present at the time did not notice it. The following morning there was still eye-fatigue and fixation difficulty, but no limp. All residual effects disappeared within 48 hours.

The results of this part of the experiment indicate that depth perception is decreased when vision is continuously disoriented, that it is to some extent improved as a result of practice, and that one's conscious adaptation to such a world likewise improves.

Part II. Effects with spaced practice.

In this part of the experiment four subjects, G., M., K. and B., were practised at 75° disorientation and limens were taken under the following conditions:

(*a*) without disorientation before practice,
(*b*) with 75° disorientation before practice,
(*c*) with 75° disorientation after practice.

A fifth subject, C., was similarly tested but was practised without disorientation. In Table I below are the results of these tests in terms of *h*, *L* and sigma as previously indicated.

Comparing conditions (*a*) and (*b*) for all subjects it is at once evident that *h* is less in the latter; in the case of subjects K. and C. it is roughly reduced to one-half the value, for subject B. to one-third, and for subjects G. and M. to one-fifth. In other words, since h is the measure of precision, disorientation decreases ability to perceive depth to a marked extent, differing in different subjects.

TABLE I.

	Subject G.			Subject M.		
Condition	h	L	sigma	h	L	sigma
(*a*)	0·0684	−0·3134	10·34	0·0605	1·4861	11·70
(*b*)	0·0136	13·0895	52·08	0·0138	11·7730	22·22
(*c*)	0·1120	0·4457	6·31	0·0731	0·8778	9·67
	Subject K.			Subject B.		
(*a*)	0·1299	1·6135	5·44	0·1842	1·0134	3·86
(*b*)	0·0683	−3·3609	10·35	0·0573	−2·7056	12·35
(*c*)	0·0600	−0·2539	11·79	0·0399	−1·7665	17·73

	Subject C.		
Condition	h	L	sigma
(*a*)	0·1686	−1·3049	4·21
(*b*)	0·0734	−1·6199	9·63
(*c*)	0·1691	−0·9895	4·18

In comparing the values of h under conditions (*b*) and (*c*), *i.e.* before and after practice with disorientation, the results are conflicting. Two of the four subjects who practised at 75° show a marked improvement in h after practice, namely G. and M. Of the other two subjects, K. shows a slight loss and B. a loss of about 30 per cent. The control subject, C., shows a considerable gain.

Taking all of these facts into consideration it is difficult to say whether improvement of depth perception with disoriented vision by means of practice is possible or not. The case of G. seems definitely affirmative. On the other hand, the improvement by subject M., who practised at 75°, is not proportionately greater than that of the control subject C., who practised only without disorientation. It may be that increased precision (or the reverse) on our test apparatus is indicative only of a degree of general adaptation to other conditions of the experiment than that of orientation of the vision field. The general question should also be considered whether highly refined limens are really more preferable to more complex quantitative measures (such as motor adjustment) as an indication of ability in a function as complicated as that of the perception of visual depth[1].

Another control subject, F., practised at a variety of disorientations, and limens were taken under the following conditions with the results set out in Table II.

---

[1] Compare Bott, Brown and Cohen (21), note, p. 10.

(*a*) Without disorientation before practice.
(*b*) With 45° disorientation before and after practice.
(*c*) With 90° ,, ,,
(*d*) With 135° ,, ,,

Table II.

Condition	Before practice			After practice		
	h	L	sigma	h	L	sigma
(*a*)	0·1837	−0·5058	3·85	—	—	—
(*b*)	0·1187	1·9357	5·91	0·0936	1·5051	7·55
(*c*)	0·0400	0·3412	17·67	0·0641	1·7278	11·04
(*d*)	−0·0924	−0·0407	7·65	−0·0994	0·9845	7·11

Here disorientation of 45° reduced precision by over one-third as measured by h; disorientation of 90° reduced it by over three-quarters; disorientation of 135° turned the measure into a minus quantity, demonstrating and giving a measure of reversed depth. These results confirm the conclusion that disorientation of vision destroys depth perception, and they indicate, moreover, that the loss of depth is in accordance with the law of orientation.

Comparing values of h before and after practice, with whatever degree of disorientation, it is seen that in this subject there is again little consistency as regards improvement following practice; under condition (*b*) there is a slight decrease, under (*c*) an increase of roughly 60 per cent., under (*d*) practically no change.

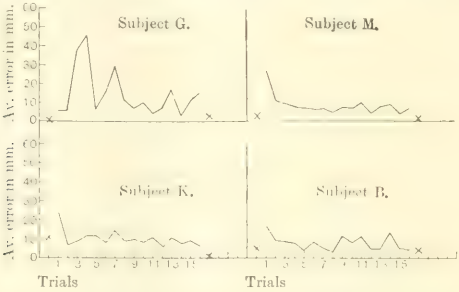
In terms of limens as determined in this investigation the weight of evidence points to the conclusion that disorientation greatly reduces depth perception but it remains uncertain whether the amount of practice we employed was sufficient to bring about improvement in this ability.

Performance on training exercises.

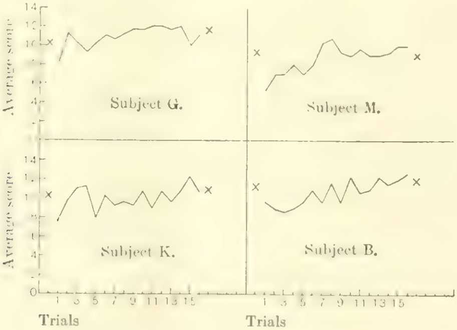
There were sixteen practices per subject, each lasting one half-hour. On the first ten occasions each subject was drilled for ten minutes on the re-education apparatus, ten minutes on the steadiness tester, five minutes on star-drawings and five minutes on the pursuit pendulum. On the last six occasions the first two exercises were allotted five minutes each, the latter two ten minutes each.

(1) *The re-education apparatus.* The scores in terms of average error in millimetres are shown in Graph 2. Inspection of these curves shows

that practically no learning took place in the cases of subjects G. and B., while subjects M. and K. showed a slight improvement. Irregularity is the chief characteristic of the performances of all subjects on this task.



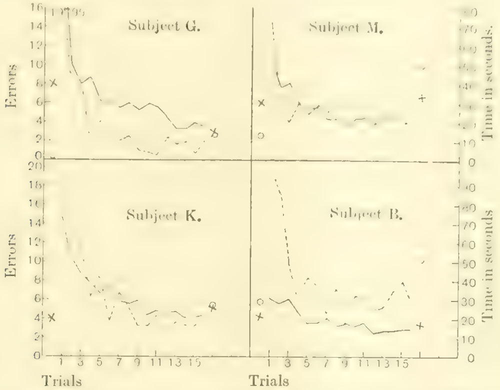
Graph 2. Performance by four subjects on re-education apparatus, 16 trials distributed over six weeks; control trials (×) were taken without disorientation.



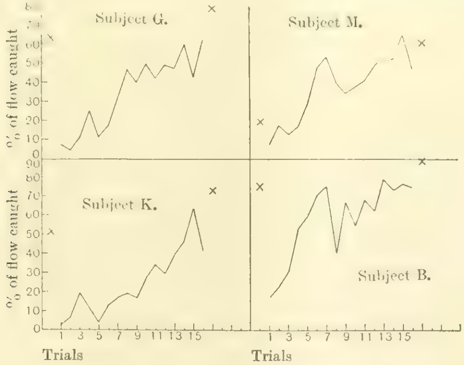
Graph 3. Performance on steadiness test, 4 subjects, disorientation 75°; controls (×) were without disorientation.

(2) *The steadiness test.* In this exercise Graph 3 shows that there was a slight amount of learning but with many gross irregularities. It is probable that factors other than visual control contributed to the unevenness of the results. Had a time limit for each hole been introduced the writer is of the opinion that the performances would have indicated a more marked degree of learning.

(3) *Star-drawings.* The results of this exercise, Graph 4, unquestionably show learning. There is a reduction in both time and error for



Graph 4. Time and error performance in star-drawing, 4 subjects, 75° disorientation; control trials (time, ×, and errors, o) were without disorientation.

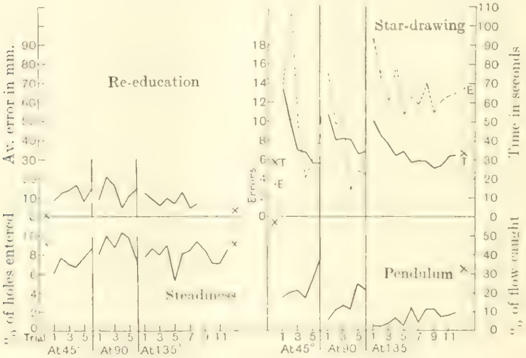


Graph 5. Performance on pursuit pendulum, 4 subjects, 75° disorientation; control trials (×) were without disorientation.

all subjects, but the time and error curves are neither parallel nor markedly opposed in their course, that is reduction in time does not imply that there were either more or fewer errors.

(4) *Pursuit pendulum.* These results as seen in Graph 5 also show a learning process. One of the characteristics of these curves is the extreme decrease in performance that sometimes occurs after a high peak of efficiency has been reached. In at least two cases the general health of the subject influenced his performance on these occasions. Another factor was the extremely keen competition which this exercise provoked, causing the subjects to work at a pitch that they found difficult to maintain.

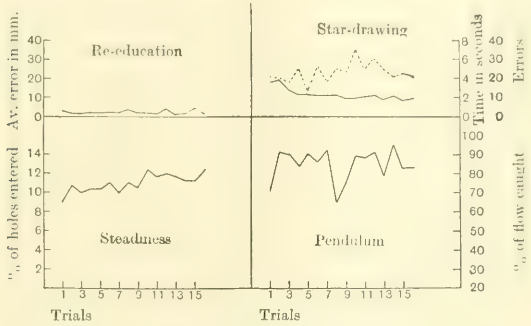
As regards the control subjects, F. had in all twenty-four practices, six at 45°, six at 90° and twelve at 135°. Each practice included work on all four exercises but the re-education apparatus was not used after the eighth practice at 135°. The complete results for this subject are given in Graph 6. As in the case of other subjects learning is not evident for F. on the re-education and steadiness exercises. The star-drawings and pursuit pendulum each show learning for all three disorientations, but to a less degree as the disorientation becomes greater. Thus six practices on the pendulum with 90° did not give as great efficiency as was attained after six practices with 45°; and twelve practices with 135° failed to produce a performance as good as that produced by six practices with 90° disorientation.



Graph 6. Performance of subject F., six trials on each of four exercises at two successive disorientations of 45° and 90°; and twelve trials on four exercises at 135° disorientation: controls (×) were without disorientation.

The performances of the control subject, C., who worked without disorientation are given in Graph 7. These give evidence of continuous slight learning in two exercises, first, there is a gradual reduction of time (but not of errors) in the star-drawings, and a somewhat irregular improvement on the steadiness test. There is an initial learning on the pursuit pendulum but a level performance of high absolute value is soon reached beyond which the subject is not able to go. Second, in the re-education exercise no learning occurs. There is throughout a greater consistency of performance than in the cases of subjects working with disorientation.

With regard to the four exercises selected to investigate the process of re-training it may be said that only two exhibited unequivocal learning, viz. the pendulum and star-drawing. The other two exercises were probably not well chosen for our purpose or perhaps not properly used. In some respects at least they do not lend themselves to show distinct improvement of performance purely on visual grounds, particularly with the limited amount of practice given. The steadiness test, for example, involves variables concerning general muscular adjustment which may markedly affect the score, and the procedure employed on the re-education apparatus probably did not canvass its possibilities as a means of re-training visual depth on the basis of dissociated kinaesthetic manipulation.



Graph 7. Performance of subject C. on four exercises without disorientation.

Concerning the relative value of carefully controlled experiential limens versus more complex measures of performance as a means of appraising ability in depth perception, the writer is inclined to favour the latter. This issue is really a question of principle in methodology, namely, of deciding how far abstraction can wisely be carried in the attempt to measure experimentally a complex process such as that of visual space perception. Merely to appeal to experiment for the answer may as easily beg this question as solve it.

Summary and Conclusions.

In this investigation the stereoscopic effects of disorienting the binocular vision field are studied. A prismatic apparatus was devised which permitted the natural field to be turned (*e.g.* clockwise) to any position through 360°. The effects of disorientation at 75° were studied in detail with four subjects and at certain other disorientations less fully with one subject. The subjects were given occasional practice on manual-visual exercises in the attempt to ascertain whether immediate depth perception is an acquirable function under such conditions. One subject maintained disoriented vision at 75° continuously for one week with introspections on the experience. Quantitative results on the exercises were taken and also limens of depth perception under a variety of disorientation conditions before and after practice.

The following conclusions seem warranted from the data:

1. Disorientation of the binocular vision field decreases the ability to perceive immediate depth as judged by perceptual limens and by overt performance.

2. The loss of depth varied directly with the amount of disorientation in accordance with the law of orientation. This law thus holds for the natural vision field as well as for stereoscopic photographic materials.

3. The evidence is not conclusive that practice with disoriented vision will restore or greatly improve the ability to perceive depth, but there are indications that with adequate practice considerable improvement might be expected.

4. There are individual differences both in the amount of loss and of recovery of depth with disorientation.

5. On introspective evidence as well as objective, adaptation to the experience of disoriented vision proceeds consistently as a result of practice.

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APPENDIX.

Sample computation of the measures h, L and sigma.

The data below are those of subject G. taken with 75° disorientation after practice. Ten judgments of 'far' or 'near' were made of screen S_2 with respect to S_1 at fifteen different positions, namely, one even with S_1, at seven successive equal steps in front of S_1 and seven similar steps at back of S_1. The size of these steps for subject G. by preliminary empirical determination was 1 mm. The 150 presentations of stimulus S_2 were given in miscellaneous order.

In the table of data:

S is the stimulus distance in millimetres of the movable screen from the stationary one, plus meaning in front and minus behind.

X is the unit distance or interval employed in the given case, *e.g.* 1 mm.

P is the percentage of subject's reports given as 'near' for each stimulus position.

W, gamma W, XW, X^2W, WX gamma are obtained from Urban's tables; the totals of these columns as shown at the right are checked for accuracy by Rich's tables.

S	X	P	W	gamma W	XW	X^2W	WX gamma	Total
+7	+7	70	0·9043	0·3353	6·3298	44·3087	2·3471	54·2252
+6	+6	90	0·5376	0·4871	3·2253	19·3518	2·9228	26·5246
+5	+5	90	0·5376	0·4871	2·6878	13·4388	2·4356	19·5869
+4	+4	80	0·7695	0·4579	3·0780	12·3120	1·8317	18·4491
+3	+3	90	0·5376	0·4871	1·6126	4·8380	1·4614	8·9367
+2	+2	40	0·9768	−0·1750	1·9537	3·9074	−0·3501	6·3128
+1	+1	50	1·0000	0	1·0000	1·0000	0	3·0000
0	0	50	1·0000	0	0	0	0	1·0000
−1	−1	40	0·9768	−0·1750	−0·9768	0·9768	0·1750	0·9768
−2	−2	20	0·7695	−0·4579	−1·5390	3·0780	0·9159	2·7665
−3	−3	20	0·7695	−0·4579	−2·3085	6·9255	1·3738	6·3024
−4	−4	10	0·5376	−0·4871	−2·1502	8·6008	1·9485	8·4496
−5	−5	40	0·9768	−0·1750	−4·8842	24·4212	0·8753	21·2141
−6	−6	20	0·7695	−0·4579	−4·6170	27·7020	2·7476	26·1442
−7	−7	10	0·5376	−0·4871	−3·7628	26·3400	3·4099	26·0376
			11·6007	−0·6184	−0·3513	197·2010	22·0945	229·9265

h^1 is obtained by applying the following formula:

$$h^1 = \frac{\Sigma W \,.\, \Sigma W X \text{ gamma} - \Sigma \text{ gamma } W \,.\, \Sigma X W}{\Sigma W \,.\, \Sigma X^2 W - (\Sigma X W)^2}$$

$$\frac{11{\cdot}6007 \text{ by } 22{\cdot}0945 - (-{\cdot}6184) \text{ by } (-{\cdot}3513)}{11{\cdot}6007 \text{ by } 197{\cdot}2010 - (-{\cdot}3513)^2}$$

$$= {\cdot}1120.$$

$$h = \frac{h^1}{d}, \text{ where } d \text{ is the unit interval, } e.g. \ 1.$$

Hence $h = {\cdot}1120$.

L is obtained as follows:

$$L^1 = \frac{h^1 \text{ by } \Sigma X W - \Sigma \text{ gamma } W}{h^1 \text{ by } \Sigma W}$$

$$= + {\cdot}4457.$$

$$L = M - dL^1,$$

where M is the mid-point of the scale, *i.e.* in this case zero.

Hence $L = - {\cdot}4457$.

Sigma is $\dfrac{1}{h \text{ by sq. root of } 2}$

$= 6{\cdot}3131.$

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